Impact Evaluation of 2014 RI Prescriptive Compressed Air Installations

National Grid

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1 EXECUTIVE SUMMARY

This report presents the results of DNV GL's Impact evaluation for National Grid's 2014 Prescriptive Compressed Air (CAIR) installations' in Rhode Island (RI). This program in RI is offered only for New Construction Compressed Air projects. These results serve many purposes including independent estimation of program and measure gross savings, and provide findings and recommendations to improve programs and projects and measure effectiveness.

1.1 Evaluation Background

This study presents final realization rates for Prescriptive CAIR energy efficiency measures installed in 2014. The site specific results were aggregated to determine realization rates separately for National Grid's prescriptive CAIR program in RI and MA combined. This evaluation's results were added to a previously completed Massachusetts (MA) sample (National Grid territory) to determine the overall impact of the program. And the combined sample for the study was designed in consideration of the 90% confidence level for energy (kWh) with ±10% precision.

1.2 Evaluation Objectives

The objectives of this Impact Evaluation of 2014 Prescriptive CAIR Installations are to verify and validate the energy and demand savings claims through site specific inspection, monitoring and analysis. The results of this study will be used to determine the final realization rates for Prescriptive CAIR energy efficiency measures installed in 2014. In addition, the impact evaluation provides new deemed savings estimates, savings algorithms and/or savings factors to be used to inform future savings estimates. The evaluation sample for this study was designed in consideration of the 90% confidence level for energy (kWh).

1.3 Summary of Approach

DNV GL conducted the following steps in order to achieve the research objectives and ensure the Sponsors' satisfaction with this Prescriptive CAIR:

- Designed an efficient sampling plan for the selection of Prescriptive CAIR participants for on-site visits, optimized to the extent possible to result in energy savings estimates with ±10% precision at the 90% confidence interval for all selected end uses in both MA and RI combined National Grid territory level;
- Developed a project work plan outlining the major approaches and addressing foreseeable research issues of this impact evaluation effort;
- Reviewed the formulas, underlying calculations, and factors used in the development of the tracking savings for each sampled participant to develop measure specific M&V plans;
- Performed comprehensive data collection at each sample site to support an independent analysis of adjusted gross energy and demand savings realization rates; and
- Produced comprehensive reporting of results, including final sample plans, data collection methods, analysis techniques, and finally presenting findings and recommendations to improve program and projects.

1.4 Results

National Grid utilizes the TRM savings methodology to produce savings estimates for compressed air measures. The current program covers only new construction or time-of-failure installations. The air compressor types rebated include:

- Load/No Load – 15 HP to 24 HP
- Load/No Load – 25 HP to 75 HP
- Variable Speed Drive (VSD) – 15 HP to 24 HP
- VSD – 25 HP to 75 HP
- Variable Displacement – 50 HP to 75 HP

In addition to the air compressors listed above, the current CAIR program includes rebates for Efficient Refrigerated Air Dryers, Low Pressure Drop Filters, and Zero Loss Condensate Drains. For this impact evaluation, the DNV GL team selected a total sample of 36 air compressor sites in which 32 sites were completed in a recent MA study[1] and 4 sites were completed in RI. All compressed air measures were evaluated at each selected site. The final sample included 36 air compressors, including 33 in the largest category, VSD 25 to 75 HP. Within these 36 sampled sites, there were 32 secondary measures; 17 refrigerated air dryers and 15 zero loss condensate drains installed. This evaluation produced prospective realization rates for each measure type.

In the case of the compressed air savings evaluation, DNV GL again produced realization rates which compared the modeled measure savings estimates to the National Grid's program tracking database savings estimates, as well as updated key assumptions and parameters to be used in the TRM savings methodology for any prospective applications.

1.4.1 Air Compressor

Table 1-1 presents the realization rates for all air compressors (types) and calculated relative precision at 90% confidence at state-level. One point to note here is that these realization rates are calculated against the gross annual energy savings (kWh) taken from the National Grid's tracking database, which includes the TRM defined baseline of a modulating compressor with blowdown. DNV GL determined the overall (MA+RI) CAIR program realization rate to be 118% with 90% confidence at ±12.2% precision.

Table 1-1: Air Compressor Gross kWh Savings Realization Rates by State

State	Total Tracking Savings (kWh)	Total Evaluation Savings (kWh)	Realization Rate	Relative Precision at 90% Confidence
MA	3,624,381	4,471,422	123.4%	±13.5%
RI	1,051,079	1,023,085	97.3%	±34.3%
Overall	**4,675,460**	**5,494,508**	**118%**	**±12.2%**

[1] Impact Evaluation of 2012 and 2013 Prescriptive Chiller and Compressed Air Installations in MA

These realization rates were the result of two primary factors: calculated air compressor kW/HP savings factors using actual compressor loading measurements and measured operating hours as compared to hours provided by customers for each application.

For prospective use, the evaluators developed Table 1-2, which presents the weighted average kW per HP saved values for all air compressors and also for the VSD 25 to 75 HP compressors only. These savings values are calculated as the weighted average kW per HP savings across all operating hours. As a comparison, the TRM assumption for kW/HP saving for the VSD 25 -75 category is 0.228 kW/HP saved.

The evaluators calculated the savings factors using two different baselines: the TRM baseline, or modulating with blow down, and a load/unload baseline. Results using a load/unload baseline were produced given the recommendation to use that as baseline in the future (see recommendations below). As shown in the Table 1-2, the savings produced using the two baselines are not significantly different. This means that at the loads observed in this study, both baseline compressor types would have operated at nearly the same kW. The load/unload compressor is similar in efficiency to the modulation with blowdown compressor unless storage increases from the minimum one gallon per CFM, in which case the efficiency of the load/unload compressor would improve. The evaluation recommends shifting the baseline to a load/unload controls, in which case, the VSD 25-75 HP, load/unload result of 0.190 kW/HP would be recommended for use in the updated TRM calculations.

Table 1-2: Evaluated Air Compressor kW/HP Saved by Baseline Type

Compressor Type	Number of Compressors	kW per HP Saved	
		Modulating w/ Blowdown Baseline (TRM)	Load/Unload Baseline
All Air Compressors – Including VSD 25 – 75 HP	36	0.125	0.127
	RP @ 90% Confidence	±10.94%	±11.94%
	RP @ 80% Confidence	±8.53%	±9.31%
VSD 25 - 75 HP	33	0.181	0.190
	RP @ 90% Confidence	±8.15%	±8.78%
	RP @ 80% Confidence	±6.35%	±6.84%

The evaluation calculated average operating hours for all air compressors and all VSD 25 to 75 HP air compressors. Operating hours are defined as all hours the compressors are on, which are indicated in the metered data by a power draw of greater than 0.1 kW. The operating hour results are presented in Table 1-3 along with the weighted average tracking estimates for operating hours. The tracking hours are not stipulated in the TRM, but are provided by customers for each application. As shown below, the evaluation found significantly higher operating hours from monitored data as compared to the tracking estimates.

Table 1-3: Air Compressor Average Operating Hours

Compressor Type	Number of Compressors	Tracking Hours	Evaluation Hours	Evaluated/Tracking Hours
All Air Compressors	36	3,864	5,569	144%
VSD 25 - 75 HP	33	4,959	6,978	141%

This evaluation also produced prospective adjusted savings factors and coincidence factors for summer and winter peak demands. These savings factors should only be applied to future air compressor projects that use the updated TRM methodology. This methodology would retain the existing algorithms, but would use the following updated components in the savings estimates:

- Rated HP
- kW/HP Savings Factor – VSD 25 – 75 HP, Load/Unload baseline results from this study
- Hours of Use Adjustment (kWh RR) – 141% from this study, applied in the TRM as a kWh realization rate
- Peak Coincidence Factors – (MA+RI) Values for Summer and Winter On-Peak or (See Table 1-4)

Table 1-4: Air Compressor Summer and Winter Peak Coincidence Factors

Compressor Type	Summer On-Peak kW CF	Winter On-Peak kW CF
All Air Compressors	1.000	0.82
Relative Precision at 80% Confidence	±9.38%	±11.65%
VSD 25 - 75 HP	1.05	0.83
Relative Precision at 80% Confidence	±10.46%	±15.12%

1.4.2 Refrigerated Air Dryer

A combined 17 Refrigerated Air Dryers were sampled in MA (16 sites) and RI (1 site) in a population of 119 installations. Table 1-5 provides the weighted average kW per CFM saved values for all refrigerated dryers. The table provides the weighted averages of the tracking value, which was derived from the gross kWh tracking savings, the TRM value, and the evaluated value. The evaluated value was significantly higher than either the tracking/TRM values. The evaluation found that when the compressor systems operated, the new cycling dryers were off more often than estimated, while the baseline, non-cycling dryers, would have run during all compressor hours, which were significantly longer than estimated. The evaluation value should override the current TRM value.

Table 1-5: Dryer kW per CFM Saved

		kW Saved per CFM		
Equipment	Number of Dryers	Tracking Value	TRM Value	Evaluation
All Refrigerated Dryers	17	0.00382	0.00371	0.00558
	RP @ 90% Confidence			22.5%
	RP @ 80% Confidence			17.5%

The evaluation calculated average operating hours for all air dryers. Operating hours are defined as all hours the compressors are on, which are when the dryers would realize savings. The evaluation found the weighted average operating hours of the dryers to be 6,944 hours per year compared to the tracking estimate of 4,460 hours per year. The tracking hours are not stipulated in the TRM, but are based on customer provided inputs on the application. The evaluation found significantly higher operating hours from monitored data as compared to the tracking estimates. These hours correspond with the air compressor hours presented above.

Table 1-6 provides the hours of use realization rate, which should be used prospectively when combined with the updated kW per CFM savings factor above.

Table 1-6: Dryer Hours of Use Realization Rate

Equipment	Number of Dryers	Hours of Use		
		Tracking Value	Evaluation Value	Realization Rate
All Refrigerated Dryers	17	4,460	6,944	155.7%
	RP @ 90% Confidence			46.62%
	RP @ 80% Confidence			35.47%

1.4.3 Zero Loss Condensate Drains

This study looked at all incentivized zero loss condensate drains that were included with the air compressor sample. The evaluation verified zero loss condensate drains were installed at all of the 15 sites that had them listed in their tracking estimates. One site (in MA) was missing one of the four incentivized drains. Overall, savings were recalculated by updating the compressor run hour component of the savings calculation with the compressor run hours from the monitored data. The result was that the zero loss drains were found to save approximately 99.7% of the estimated energy savings across the 15 sites.

It appears that the drains are installed and seem to be working properly, but performance was not assessed.

1.5 Conclusions and Recommendations

This evaluation found that savings from all three prescriptive compressed air measures are being realized. The air compressor measure produced an energy savings (kWh) realization rate of 118%. This value was primarily driven by VSD air compressors, which performed much better (121%) than the load/unload air compressors (12%). However, it should be noted that there was only one (1) load/unload air compressor in the sample. The high VSD compressor realization rates were primarily the result of higher than the anticipated operating hours.

The dryer measure yielded an energy savings realization rate of 156%, which was driven by both a higher average kW reduction per CFM, and higher operating hours. The largest savings increase came from the largest dryer category (>400 CFM). This dryer category included five dryers, which were all part of compressed air systems that operated 24/7.

The zero loss condensate drains appear to be installed as expected. Though this equipment was not monitored, evaluators verified the installation of almost all drains that were incentivized. This evaluation does not recommend any adjustments to the zero loss condensate drain measure due to a small sample size.

1.5.1 Air Compressor Baseline

The evaluation calculated air compressor savings using two different baselines, including the current modulating baseline with blowdown and a load/unload baseline. Though the results did not vary significantly between the two, this evaluation recommends updating the baseline to a load/unload baseline going forward. A recent incremental cost study[2] found that the cost of a modulating air compressor is nearly the same as a load/unload air compressor, and that the load/unload air compressor is now considered the baseline compressor. This finding was based on interviews with four compressed air sales representatives. The results of this study show that the savings opportunities from going from a modulating to load/unload system are minimal except at higher storage levels for the load/unload unit.

1.5.2 Application of Results

This study produced new savings factors for air compressors and refrigerated dryers to be used prospectively, as shown in Table 1-7. These savings factors, which are calculated based on the average operating kW of the sample of air compressors and dryers, may be used to update the values in the TRM. This table includes the savings factors for both baselines. Should the program switch to a load/unload baseline, the TRM should use the new load/unload values.

Table 1-7: Air Compressor and Dryer kW Savings Factors

Equipment	Air Compressors		Refrigerated Dryers
	kW Reduction per HP (Modulating w/ Blowdown)	kW Reduction per HP (Load/Unload)	kW Reduction per CFM
All Air Compressors	0.125	0.127	N/A
VSD 25 – 75 HP	0.181	0.190	N/A
All Refrigerated Dryers	N/A	N/A	0.00558

It is also recommended that National Grid apply the new air compressor coincidence factors to both the zero loss condensate drain and low pressure drop filter measures, since the savings for these measures occur during compressor operation.

1.5.3 General Recommendations

Recommend compressed air vendors conduct simple short term metering. Customers often don't know how their air compressors operate during off-shift periods. While the customer may be able to accurately report the hours of normal shift operations, compressed air systems nearly always have some leaks or other air users that, if not shut off, the compressor will continue to feed during off-shift hours. While this is a prescriptive program, which is intended to be streamlined, collecting very simple short-term data prior to specifying hours of operation on an application would help improve the accuracy of the annual hours of operation. This type of metering could be done by the vendor, and could be a simple as a week of motor runtime. Another option would be to investigate the incremental cost of adding monitoring at the time of compressor installation as part of the incentive package. Compressed air system monitoring would help operators understand and manage their air use while providing the industry with more compressed air energy data.

[2] Navigant, Northeast Energy Efficiency Partnerships Inc. (NEEP) Incremental Cost Study Phase Four Final Report. June 15, 2015. P. 21.

Consider a review of hours of operation prior to finalizing applications. In many cases the actual operating hours were observed to be significantly higher than entered on the application form, resulting in unclaimed savings. For applications with relatively low operating hours (<~4,000 hrs/yr), it may be worthwhile to perform a brief operational hours review to confirm actual plant operating hours. Compressors are often a significant percentage of a facility's energy consumption and operation is noticeable in the interval load data. Increased operating hours result in increased savings from a higher efficiency compressor.

Encourage vendors to look for additional compressed air savings opportunities. In most cases the compressors appeared to be operating at the same discharge pressure as prior to installation based on discussions with facility personnel. While the customer is engaged with upgrading their compressed air system, it may be worthwhile to investigate operation at a lower discharge pressure. Additional savings will result if the discharge pressure can be reduced. Likewise, consider performing an air leak survey to determine if additional savings can be realized from reducing air leaks. Reducing leaks may, in some cases, result in being able to purchase a smaller compressor saving more money. These types of improvements are covered by the custom program, and may result in moving some prescriptive air compressor projects to custom.

2 INTRODUCTION

This report presents the results of DNV GL's Impact Evaluation of 2012/13 (MA) and 2014 (RI) Prescriptive Compressed Air (CAIR) Installations for National Grid.

2.1 Evaluation Background

This study presents final realization rates for Prescriptive CAIR energy efficiency measures installed in 2014. The site specific results were aggregated to determine realization rates separately for National Grid's prescriptive CAIR program in RI and MA combined. This evaluation's results were added to a previously completed Massachusetts (MA) sample (National Grid territory) to determine the overall impact of the prescriptive CAIR program. The combined sample for the study was designed in consideration of the 90% confidence level for energy (kWh) with ±10% precision.

2.2 Evaluation Objectives

The objective of this Impact Evaluation of 2014 Prescriptive CAIR Installations is to provide verification or re-estimation of gross energy (kWh) and demand (kW) savings through site specific inspection, monitoring and analysis. The results of this study will be used to determine the final realization rates for Prescriptive CAIR energy efficiency measures installed in 2014. In addition, the impact evaluation provides new deemed savings estimates, savings algorithms and/or savings factors to be used to inform future savings estimates. The evaluation sample for this study was designed in consideration of the 90% confidence level for energy (kWh) and 80% for coincident peak summer demand (kW).

2.3 Summary of Approach

DNV GL conducted the following steps in order to achieve the research objectives and ensure the Sponsors' satisfaction with this Prescriptive CAIR:

- Designed an efficient sampling plan for the selection of Prescriptive CAIR participants for on-site visits, optimized to the extent possible to result in energy savings estimates with ±10% precision at the 90% confidence interval for all selected end uses in both MA and RI combined National Grid territory;
- Developed a project work plan outlining the major approaches and addressing foreseeable research issues of this impact evaluation effort;
- Reviewed the formulas, underlying calculations, and factors used in the development of the tracking savings for each sampled participant to develop measure specific M&V plans;
- Performed comprehensive data collection at each sample site to support an independent analysis of adjusted gross energy and demand savings realization rates; and
- Produced comprehensive reporting of results, including final sample plans, data collection methods, analysis techniques, and finally presenting findings and recommendations to improve program and projects.

3 PRESCRIPTIVE HIGH EFFICIENCY COMPRESSED AIR

This section documents the results from the impact evaluation of Prescriptive High Efficiency Air Compressor installations in the National Grid territory of both RI and MA. This evaluation reviewed the projected savings for prescriptive high efficiency air compressors as defined in the Rhode Island Technical Reference Manual[3] (TRM) dated November 2013. The current program covers only new construction or time-of-failure installations. The air compressor types rebated include:

- Load/No Load – 15 HP to 24 HP
- Load/No Load – 25 HP to 75 HP
- Variable Speed Drive (VSD) – 15 HP to 24 HP
- VSD – 25 HP to 75 HP
- Variable Displacement – 50 HP to 75 HP

In addition to the air compressors listed above, the current program includes rebates for Efficient Refrigerated Air Dryers, Low Pressure Drop Filters, and Zero Loss Condensate Drains.

This section presents the following items:

- Tracking Savings Review
- Sample Design
- Data Collection Methods
- Analysis Methodology
- The Results of our Evaluation

3.1 Tracking Savings Review

Tracking energy (kWh) and demand (kW) savings for each air compressor measure were derived from applying stipulated impact factors provided in the TRM to the equations and input variables used for each measure. Some site-specific variables (e.g. annual operating hours, compressor size and type) are incorporated to calculate annual energy savings. The prescriptive savings variables, site-specific input factors, and savings equations are described below for each measure.

3.1.1 High Efficiency Air Compressors

This measure covers the installation of oil flooded, rotary screw compressors with load/no-load controls, variable speed drive, or variable displacement capacity control and a properly sized air receiver. Prescriptive savings are based upon compressor size, control type, and site specific operating hours. Only compressors that are ≥ 15 HP and ≤ 75 HP qualify for prescriptive incentives, and project applications specify additional compliance limits, e.g. maximum operating pressure and minimum annual run hours. Table 3-1 shows the prescriptive per horsepower savings factors for the applicable equipment in this measure.

[3] Rhode Island Technical Resource Manual: For Estimating Savings from Energy Efficiency Measures (PY2014)

Table 3-1: Air Compressor kW Reduction per Horsepower[4]

Control Type	Nominal Horsepower (HP)	kW Reduction per HP (Save)
Load/No Load	≥15 and <25	0.076
Load/No Load	≥25 and <=75	0.114
VSD	≥15 and <25	0.159
VSD	≥25 and <=75	0.228
Variable Displacement	≥50 and <=75	0.110

Algorithms for Calculating Primary Energy Impacts:

$$\Delta kWh = (HPcompressor)(Save)(Hours)$$

$$\Delta kW = (HPcompressor)(Save)$$

Where:

$HP_{compressor}$ = Nominal rated horsepower of high efficiency air compressor

Save = kW reduction per motor HP and control type [Table 3-1]

Hours = Annual operating hours of the air compressor provided for each application

Summer and winter peak demand impacts are further calculated using the gross ΔkW listed above and coincidence factors provided in the TRM.

Baseline Efficiency:

The baseline efficiency case is a typical modulating compressor with blow-down valve. The inlet valve modulation throttles off the air inlet to a compressor as the discharge pressure rises above the set-point pressure, thus causing the compressor to draw in less air, matching compressor capacity with air usage for relatively steady pressure control. Unfortunately, the part-load performance of modulating compressors is relatively poor. Hence, modulation-controlled machines may be adjusted to fully unload or "blow down" if capacity reduces to a certain level, such as 40%. This reduces energy consumption, but typically involves the use of air storage receivers to meet demand when the compressor is in the fully unloaded state.

High Efficiency:

The high efficiency case is a lubricant-flooded, rotary screw compressor with Load/No Load, Variable Speed Drive, or Variable Displacement capacity control with a properly sized air receiver for storage.

With Load/No Load control, the air compressor will unload when the system pressure is met, and reload when the system pressure falls below a set point. An adequately sized air receiver will make

[4] These values are for New Construction or Lost Opportunity measures only.

this type of system more efficient by providing properly pressurized stored air and allowing the air compressor to fully unload.

Air receivers are designed to provide a supply buffer to meet short-term demand spikes which can exceed the compressor capacity. Installing a larger receiver tank to meet occasional peak demands can allow for the use of a smaller compressor. More detailed rules regarding primary storage requirements are listed on the project application.

A variable speed drive allows the motor to operate proportionally to the air flow, which increases efficiency as compared to a constant speed compressor. Energy savings for this type of compressor are generally highest at lower to mid-range air flows. A variable displacement capacity control allows for a reduction of compressor displacement without reducing the inlet pressure. This type of control will provide variable displacement down to about 50% capacity followed by unloading.

Hours:

The annual hours of operation for air compressors are site-specific and are determined on a case-by-case basis for each application. These are the run hours of the compressor and not the operating hours of the facility.

3.1.2 Efficient Refrigerated Air Dryers

This measure installs cycling refrigerated air dryers or refrigerated air dryers equipped with variable frequency drives, to reduce the runtime and/or instantaneous power consumed by typical dryers. These dryers are usually installed to remove moisture that could otherwise condense in pressurized system lines and result in corrosion and increased maintenance costs. The efficient cycling air dryers turn the refrigeration compressor on and off according to compressed air flow, temperature and moisture of air. Variable speed drive equipped refrigerated air dryers affect compressor speed according to compressed air flow and temperature. This measure is applicable only for single compressor systems. Table 3-2 provides the prescriptive kW savings values per CFM of dryer capacity. The TRM employs the same savings factors for cycling and VSD equipped refrigerated dryers. Annual operating hours are site-specific.

Algorithms for Calculating Primary Energy Impact:

$$\Delta kWh = (CFM_{dryer})(Save)(Hours)$$

$$\Delta kW = (CFM_{dryer})(Save)$$

Where:

CFM_{dryer} = Full flow rated capacity of the refrigerated air dryer in cubic feet per (CFM). Obtain from equipment's Compressed Air Gas Institute (CAGI) Datasheet

Save = Refrigerated air dryer kW reduction per dryer full flow rated CFM per

Hours = Table 3-2

Table 3-2: kW Reduction per CFM by Dryer Capacity (Save)

Dryer Capacity (CFM)	kW Reduction per CFM
<100	0.00474
≥100 and <200	0.00359
≥200 and <300	0.00316
≥300 and <400	0.00290
≥400	0.00272

Baseline Efficiency:

The baseline efficiency case is a non-cycling refrigerated air dryer.

High Efficiency:

The high efficiency case is a cycling refrigerated dryer or a refrigerated dryer equipped with a VFD.

Hours:

The annual hours of operation for compressed air dryers are site-specific estimates provided for each application.

3.1.3 Zero Loss Condensate Drains

This measure installs zero loss condensate of drains to remove water from a compressed air system. Zero loss condensate drains remove water from a compressed air system without venting any air, resulting in less air demand, lower pressure drop than standard drains and consequently greater overall system efficiency. This measure is applicable to single compressor systems that are ≤ 75 horsepower in size. The compressed air CFM and annual operating hours are site-specific values.

Algorithms for Calculating Primary Energy Impacts:

$$\Delta kWh = (CFM_{pipe})(CFM_{save})(Save)(Hours)$$

$$\Delta\, kW = (CFM_{pipe})(CFM_{save})(Save)$$

Where:

ΔkWh	=	Annual energy Savings
ΔkW	=	Demand savings
CFM_{pipe}	=	CFM capacity of piping. Site-specific.
CFM_{save}	=	Average CFM saved per CFM of piping capacity: 0.049 (dimensionless)
Save	=	Average savings per CFM: 0.24386 kW/CFM. Stipulated constant.
Hours	=	Annual operating hours of the zero loss condensate drain.

Baseline Efficiency:

The baseline efficiency case is installation of a standard condensate drain on a compressor system.

High Efficiency:

The high efficiency case is installation of a zero loss condensate drain on a single operating compressor rated ≤ 75 HP.

Hours:

The annual hours of operation are site-specific and will be determined on a case by case basis

3.2 Sample Design

3.2.1 Population Review

The purpose of this task was to identify the impact category's sampling population and understand its relative impact on the overall 2014 RI prescriptive CAIR projects. DNV GL utilized the 2014 data received as part of our recent customer profile analysis to complete this review. A comparison of the prescriptive CAIR projects' population data for both MA and RI states is presented in Table 3-3.

Table 3-3 Population of Prescriptive CAIR Projects in MA and RI

State	Projects	Total Savings kWh	Average Savings kWh	Minimum kWh	Maximum kWh	Standard Deviation	CV
MA	104	3,624,381	36,085	2,280	149,796	34,850	0.966
RI	35	1,051,079	30,031	2,371	119,837	29,108	0.969
Total	139	4,675,460					

3.2.2 Sampling Plan

Since the number of sample points required in achieving the desired level of precision depends upon the expected variability of the observed realization rates. RI Prescriptive CAIR Population data was further divided into four (4) subgroups as shown in Table 3-4. And approximately 83% energy savings was from the subgroup VSD Compressors 25-75 HP (and 71% ~3,329,090 kWh was in MA population).

Table 3-4 Measure subgroups in population (MA+RI) data

Measure Group	Projects	Tracking Savings (kWh)	% of Total Air Compressor kWh Savings
LOAD/NO LOAD 15 HP TO 24 HP	31	343,449	7%
LOAD/NO LOAD 25 HP TO 75 HP	6	171,137	4%
VSD 25 HP TO 75 HP	79	3,900,991	83%
VSD 15 HP TO 24 HP	23	259,884	6%
Total	**139**	**4,675,461**	**100%**

3.2.3 Sample Size

The primary variable of interest for the sample design was annual kWh savings. For sampling purpose first both RI and MA CAIR population data were combined and then a Stratified Ratio Estimation approach was used to develop a sample for annual kWh at the 90% confidence level. An error ratio of 0.41 was assumed based on MA 2012/13 Prescriptive CAIR Impact Evaluation results[1].The final sample design presented in this section (Table 3-6) provides for the estimation of savings results for all air compressors combined, and also for the VSD 25 to 75 HP compressor type due to its size noted in the above section. The target precision on energy savings for (MA+RI) as a whole is ±10% at the 90% confidence level.

Table 3-5 shows the stratum cut points and distribution of sample sites for the final sample design.

Table 3-5 Evaluated Sample by Measure Type

Compressor Type	Stratum	Projects (N)	Total kWh Savings	Planned Sample (n)	Weights
LOAD/UNLOAD 15 - 75 HP	1	37	514,586	1	37.00
VSD 25 - 75 HP	2	34	783,351	7	4.86
VSD 25 - 75 HP	3	20	843,136	11	2.00
VSD 25 - 75 HP	4	9	638,842	5	1.50
VSD 25 - 75 HP	5	7	613,384	2	3.50
VSD 25 - 75 HP	6	7	723,097	6	1.17
VSD 25 - 75 HP	7	2	299,182	2	1.00
VSD 15 - 24 HP	8	23	259,884	2	11.50
Totals		**139**	**4,675,461**	**36**	

Table 3-6 lists the calculated precision estimates for this scenario following stratification by compressor type and at the state level.

Table 3-6 Estimated sample precisions by State and Measure Group

Measure	Population (N)		Sample (n)	Expected Relative Precision@ 90% Confidence	Program Savings
State	**MA**	**RI**	**MA+RI**	**MA+RI**	**MA+RI**
LOAD/UNLOAD 15 - 75 HP	27	10	1	23%	11%
VSD 15 - 24 HP	17	6	2	30%	6%
VSD 25 - 75 HP	60	19	33	9%	83%
Grand Total	**104**	**35**	**36**	**8%**	**100%**

3.3 Field Data Collection

A detailed file review was performed to identify the measures installed at each of the selected sites, including refrigerated air dryers, low pressure drop filters and zero loss condensate drains. This file review started with an examination of project application for completeness and compliance with the compressed air eligibility requirements.

Once at the customer site, evaluators discussed the installed measures with facility personnel to obtain a practical overview of the compressed air system. These discussions were used to: determine if the equipment is fully operational; identify changes in equipment or operational changes made to the compressed air system after the measures were installed; and obtain additional product/equipment data required to verify the tracking savings. The installation of the proposed equipment was verified during a walk-through of the facility. Quantities of installed equipment, nameplate data, pressure readings, and other data were collected during the walk-through. As part of the site visit, evaluators asked customers about annual operating schedules, including hours and holidays, for the compressed air equipment.

A system schematic was developed, as it can be an important step in assessing the performance of a compressed air system. All compressed air supply-side components were inventoried during the site visit, including, but not limited to air compressors, storage receivers, refrigerated or desiccant air drying systems, condensate drains, and pressure/flow controllers. It was clear which measures received incentives through the program from the project application and program tracking data.

The DNV GL team installed power meters to evaluate the operation of the affected air compressors and rebated refrigerated air dryers. Evaluators also looked at any incentivized zero loss drains, but metering was not done for these measures. The metering data provides the average operating kW of the equipment and informs daily and weekly operating schedules. A summary of the metering used in this evaluation is shown in Table 3-7 below.

Table 3-7: Summary of Evaluation Metering

Measurement Variables	Air Compressor and/or Dryer (Volts, Amps, PF, kW)	Refrigerated Air Dryer (kW)	Refrigerated Air Dryer (Hours)
Measurement Equipment	Dent Elite Pro SP Power Meter Or Onset HOBO Microstation Power Meter	Yokagawa Power Meter	Dent TOU CT Logger
Installation	Clamp-on CTs and Voltage	Clamp-on CT and Voltage	Clamp-on CT
Frequency of Observations	5 minute	Instantaneous	On/Off
Duration of Metering	3 consecutive weeks minimum	Spot Measurement	3 consecutive weeks minimum
Metered by	DNV GL Team	DNV GL Team	DNV GL Team

3.4 Analysis Methodology

3.4.1 Air Compressors

The DNV GL team retrieved power loggers from the sites and downloaded the data for the analysis. The data was reviewed for consistency and, in some cases, adjusted for site specific holidays and/or closures.

An Excel spreadsheet tool was developed for this analysis, and used by all DNV GL team members. The spreadsheet tool requires Compressed Air Gas Institute (CAGI) data from installed compressors and/or air dryers. The CAGI inputs used in the analysis are: rated CFM flow capacity at full load operating power [ACFM], full load operating pressure [PSI], total package input power at zero flow [kW], and total package input power at rated capacity and full load operating pressure [kW]. The tool also requires on-site actual system discharge pressure and the amount of compressed air storage as an input. These two inputs are taken from interview with site personnel and inventory of the compressed air supply side components, including air receivers.

Other inputs that determine site savings are: installed compressor type and site-specific holidays. The baseline compressor type as determined by the program is always an inlet valve modulating compressor with blow down. The baseline air dryer is always non-cycling compared to an installed cycling air dryer. These are also pre-determined by the program.

Note that the DNV GL Team also evaluated each air compressor against an alternate load/unload baseline control type. The reason for this is that there have been discussions within the MA evaluation team regarding the appropriateness of the valve modulation baseline. Though not studied in this evaluation, there may be a shift to load/unload baselines in MA and other nearby states, including Connecticut. Therefore, the evaluation team applied the monitored data to both baselines as a comparison.

The equation below is used to adjust the full load power based on operating pressure if different from the rated pressure. This equation is based on a rule of thumb for systems in the 80 to 140 psig range, and is provided in the Compressed Air Evaluation Protocol from the Uniform Methods Project (UMP).[5] This protocol provides methods for determining energy efficiency savings for air compressors. The rule of thumb is that for every 2 psi increase in discharge pressure, energy consumption will increase by approximately 1%. This adjusted full load power was then compared to the maximum monitored kW of the air compressor.

$$kW_{MAX} = Input\ Power\ x\ [\left(1 - \frac{P_{rated} - P_{operating}}{2}\right)\ x\ 0.01]$$

Where:

kW_{MAX} = Adjusted full load input power

$Input\ Power$ = CAGI total package input power at rated capacity and full load operating pressure

P_{rated} = CAGI full load operating pressure (psi)

$P_{operating}$ = Actual system operating pressure (psi)

The compressed air analysis tool plots the baseline and installed compressor performance curves based upon the CAGI inputs provided. It looks up their performance curves from known rotary screw compressor performance curves. These curves, shown in Figure 3-1, are derived from the Compressed Air Evaluation Protocol from the UMP[6]. It lists the average performance defined as the percent power versus percent capacity for compressors of different control strategies[7]. Because the UMP only lists %power vs. %capacity for load/unload compressors of 1gal/cfm and 10gal/cfm storage, these

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[5] Chapter 22: Compressed Air Evaluation Protocol - Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures, p. 5

[6] Ibid, p. 6.

[7] Ibid, p. 13.

points are interpolated in the analysis to generate curves for systems with storage capacity between 1 gal/cfm and 10 gal/cfm.

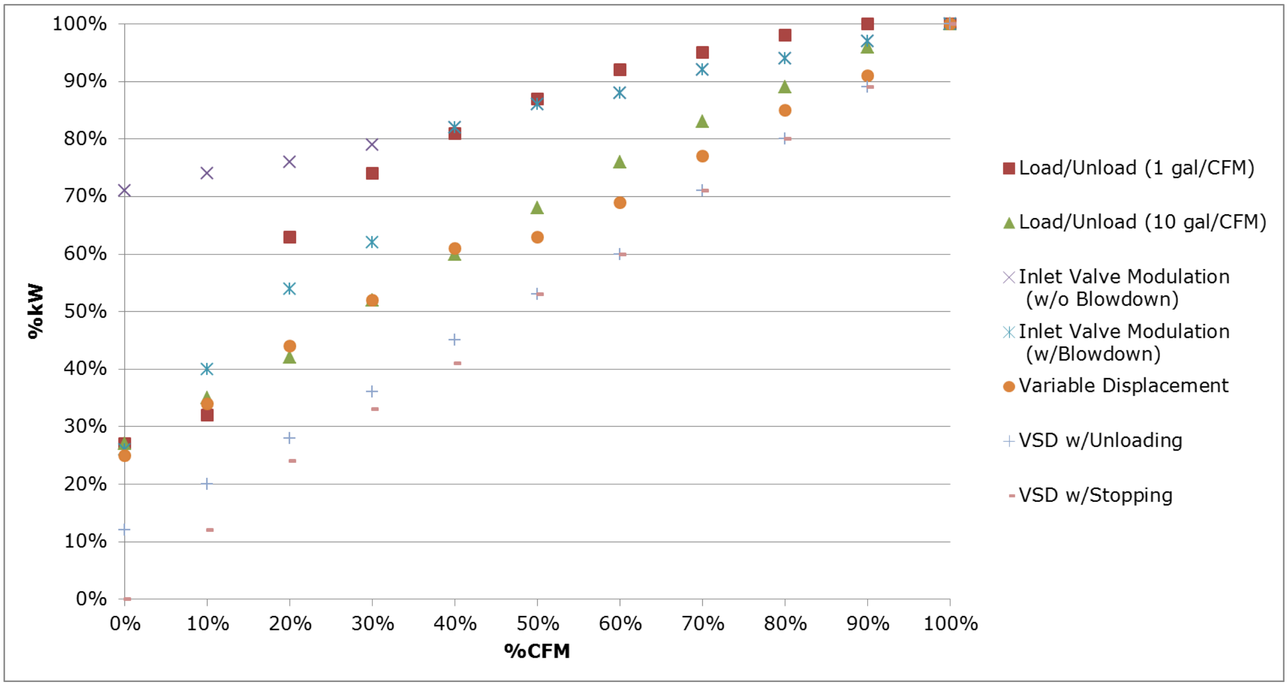

Figure 3-1: Average Percent Power vs. Percent Capacity for Rotary Screw Compressors with Various Control Methods

Along with load/unload controls, the inlet valve modulation with and without blow down, variable displacement and VSD unloading and stopping controls are plotted in Figure 3-1. These performance curves are looked up based upon which compressors are input for baseline and installed.

A regression fit is developed for each curve to determine the % full load power of the metered air compressors at each % full load flow. This regression calculates what the baseline % compressor power consumption would be from the on-site % CFM capacity. From the correlated capacity and power of the compressor, the curves are inverted to plot %CFM vs. %kW. The monitored power is then used to determine the flow at each metered data point. From this data a time series profile of compressed air usage is developed. Using that flow with the %kW versus % flow of the baseline compressor, the baseline power for that same flow is determined. The difference between that power consumption at each hour is the savings for that hour. Peak demand savings were calculated by averaging the kW savings across all defined peak hours.

From the measured on-site compressor data, four pivot tables are created by day of week and hour of day of the average installed kW, average baseline kW, average savings kW, and average percent run time. These pivot tables represent the average daily operation of the installed and baseline compressors. This is the point where manual adjustments are made for site holidays and/or shutdowns. If a holiday was logged during the monitoring period, that day was used to represent all holidays as reported by the customer. If a holiday was not monitored, evaluators used information gathered from the site contact to adjust the data for all holidays. In some cases, holidays were set to zero if the site contact said they didn't operate the compressor at all on these days. In other cases, the holidays were set to equal a weekend or Sunday profile if the site contact stated that holidays mimicked these day types. The installed and baseline kW for the monitored period are then annualized for every hour of the day and day of week to generate 8,760 savings.

Figure 3-2 and Figure 3-3 present two example sites, including a highly loaded air compressor and a lightly loaded air compressor. Each figure provides the average operating % CFM based on power monitoring conducted on each compressor. The first figure shows an air compressor that was shown to operate at an average of 57% CFM across the entire monitoring period. This operating CFM is shown plotted along with the installed compressor performance curve (VSD) and both baseline curves (Modulating and Load/Unload) to highlight the differences in power for each compressor type. The load/unload compressor would have required approximately 89% of full load power, while the modulating compressor would have required approximately 87% of full load power at this operating CFM. In this scenario, the modulating compressor would have been the more efficient baseline compressor by a slim margin.

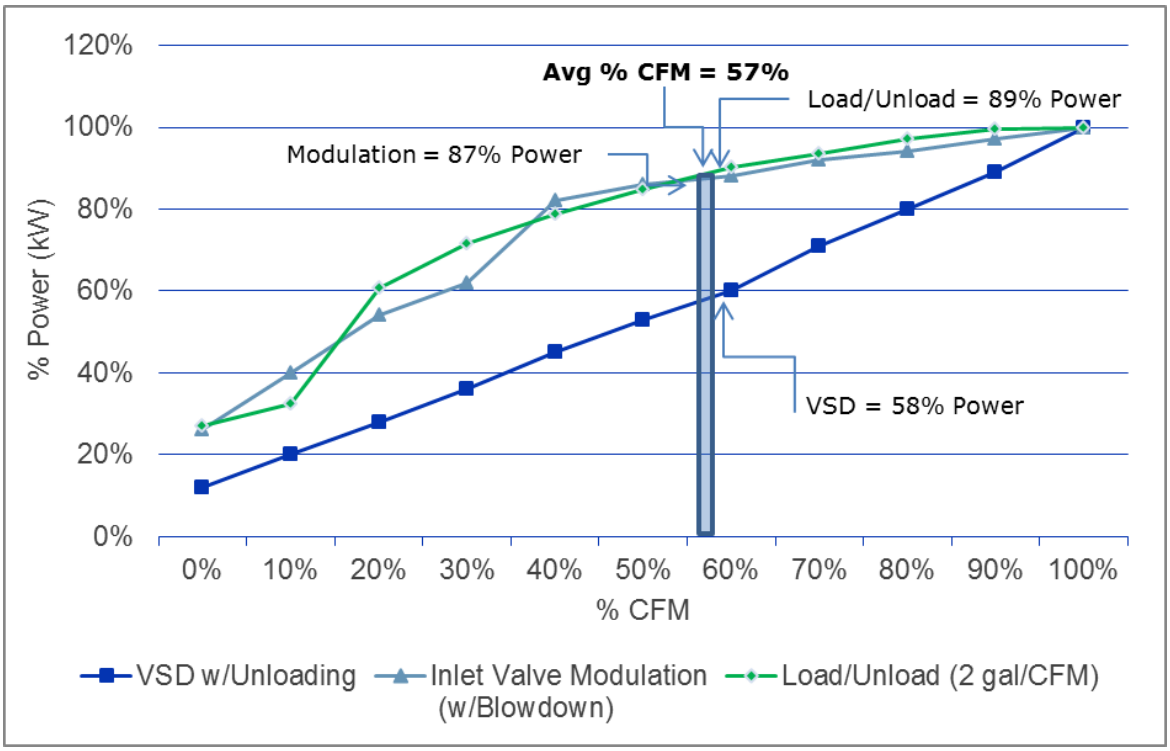

Figure 3-2: Higher Loaded Example Site Average % CFM

The lightly loaded compressor highlighted below operated at an average of 1.3% CFM across the monitoring period. In this scenario, the load/unload compressor would have been slightly more efficient than the modulating baseline compressor. In both the highly loaded and lightly loaded cases, the VSD compressors were significantly more efficient than either the modulating or load/unload compressor types.

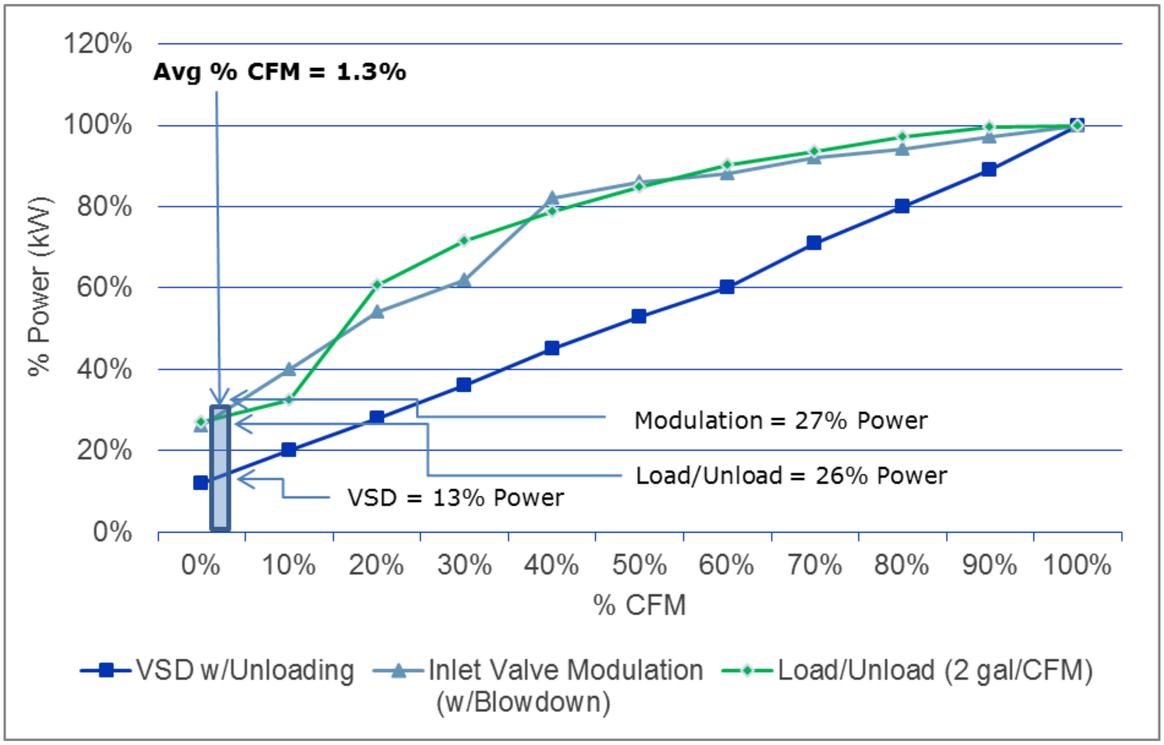

Figure 3-3: Lightly Loaded Example Site Average % CFM

3.4.2 Refrigerated Air Dryers

The DNV GL team used either time-of-use (TOU) event loggers or power loggers to monitor the refrigerated dryers that were part of the sample of air compressor projects that were evaluated. The TOU event loggers measure events when the cycling refrigerated air dryers turn on and off. Their output is measured in percent time on. Cycling refrigerated air dryers operate at a constant input power when cycled “on,” which allows for the use of TOU monitoring. Likewise, for power meters that were installed, the power data was first converted to “percent on” by dividing the metered power by the rated input power of the installed dryer. This was done so that the analysis could be conducted using a consistent parameter, “% On.” Power loggers were deployed for VSD dryers and some cycling dryers. In most cases, cycling dryers were monitored with TOU event loggers.

Once downloaded and, if necessary, converted to % on, the data were added into a separate “dryer” tab of the compressed air analysis spreadsheet tool. Along with the measured data, CAGI data of the total dryer input power is entered. This is the installed rated max operating kW of the installed dryer. Based upon the percent time on of the measured dryer, the operating kW is calculated as:

Operating kW= %On x Rated kW

The baseline air dryer as defined by the program is always a non-cycling dryer. Evaluators selected an actual non-cycling refrigerated air dryer, rated at the same flow and by the same manufacturer as the installed cycling dryer. CAGI data sheets were downloaded for each selected baseline dryer. For some non-cycling dryers, input power varies with flow. CAGI data sheets were used to estimate baseline power from % flow of the air compressor based on the rated power draw at defined airflows.

Baseline non-cycling dryers were assumed to be on at all times the compressed air system was found to operate in the compressor analysis.

3.5 Results

3.5.1 Air Compressors

3.5.1.1 Retrospective Realization Rates

Savings Results vs. Tracking

Figure 3-4 presents a scatter plot of evaluated annual kWh savings vs. tracking kWh savings for each sampled site. The dashed line represents a realization rate of 100%, while the solid line represents the actual weighted realization rate (118%) as found through this study. This scatter plot includes all sampled air compressors in MA and RI combined. The weighted realization rate for the VSD 25 to 75 HP air compressors was found to be 121% (MA+RI).

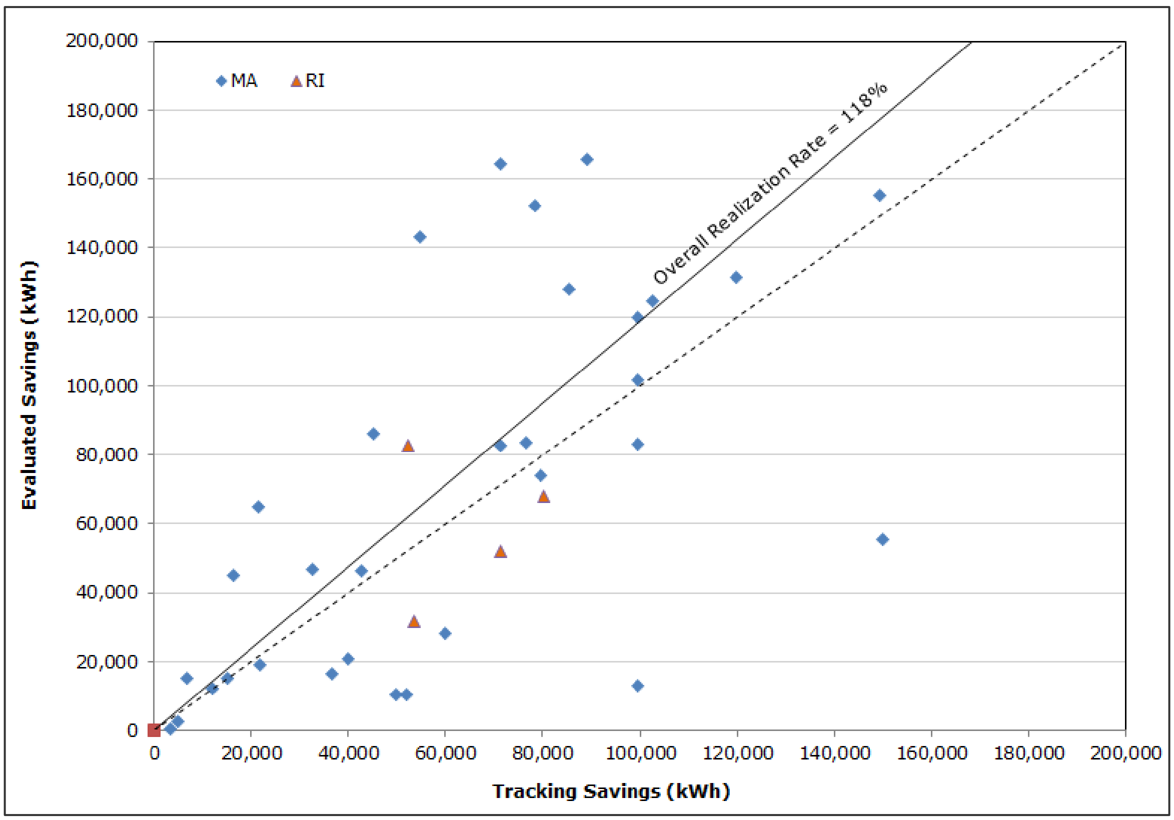

Figure 3-4: Evaluated vs. Tracking Annual kWh Savings (MA and RI)

Site Results

Table 3-8 presents the site level results for each sampled site, including the key parameters that impact the evaluated savings. These parameters include compressor HP, kW/HP saved, and annual hours. The evaluated kW per HP savings factor is calculated as the average kW savings across all operating hours divided by the rated horsepower of the installed compressor. The un-weighted average realization rate was found to be 117%.

Table 3-8: Site Level Air Compressor Results (RI only- refer MA report[1] for MA site details)

Application ID	Compressor Type	Compressor HP	Tracking				Evaluation				Annual kWh Realization Rate
			Annual kWh Savings	kW/HP	kW Savings	Hours	Annual kWh Savings	kW/HP	Average kW Savings	Annual Operating Hours	
3545577	VSD 25 - 75 HP	50	53,352	0.228	11.40	4,680	31,546	0.191	9.57	3,296	59%
3578608	VSD 25 - 75 HP	40	52,166	0.228	9.12	5,720	82,465	0.240	9.60	8,592	158%
3594985	VSD 25 - 75 HP	75	80,028	0.228	17.10	4,680	67,773	0.158	11.85	5,720	85%
4362047	VSD 25 - 75 HP	50	71,136	0.228	11.40	6,240	51,915	0.147	7.36	7,057	73%

3.5.1.2 Prospective Savings Factors

Average kW Savings

Table 3-9 provides the weighted average kW per HP saved values for all air compressors, including VSD 25 to 75 HP compressors, in the sample and for all VSD 25 to 75 HP air compressors separately. This table presents the savings values using two different baselines: the TRM baseline, or modulating with blow down, and a load/unload baseline. As shown in the table below, the differences in savings when using the two baselines are not significant. This means that at the loads observed in this study, both baseline compressor types would have operated at nearly the same kW. This is highlighted in Figure 3-1, which shows that the load/unload curve closely matches the modulation with blowdown curve at points above 30% loading. The evaluation recommends shifting to a load/unload baseline, in which case, the VSD 25-75 HP, load/unload result of 0.190 kW/HP would be recommended for use in the updated TRM calculations.

Table 3-9: Air Compressor kW per HP Saved by Baseline Type

Compressor Type	Number of Compressors	kW Reduction per HP Saved	
		Modulating w/ Blowdown Baseline (TRM)	Load/Unload Baseline
All Air Compressors – Including VSD 25 – 75 HP	36	0.125	0.127
	RP @ 90% Confidence	±10.94%	±11.94%
	RP @ 80% Confidence	±8.53%	±9.31%
VSD 25 - 75 HP	33	0.181	0.190
	RP @ 90% Confidence	±8.15%	±8.78%
	RP @ 80% Confidence	±6.35%	±6.84%

The kW per HP savings value for VSD 25 to 75 HP air compressors was found to be 0.181 with a modulating baseline. This is approximately 80% of the TRM estimate of 0.228 kW/HP saved.

Operating Hours

The evaluation calculated average operating hours for all air compressors and all VSD 25 to 75 HP air compressors. Operating hours are defined as all hours the compressors are on, which are based on a power draw of greater than 0.1 kW. These results are presented in Table 3-10 along with the weighted average tracking estimates for operating hours. The tracking hours are not stipulated in the TRM, but are based on site conditions. As shown below, the evaluation found significantly higher operating hours from monitored data as compared to the tracking estimates.

Table 3-10: Weighted Average Compressor Operating Hours

Compressor Type	Number of Compressors	Tracking Hours	Evaluation Hours	Evaluated/Tracking Hours
All Air Compressors	36	3,864	5,569	144%
VSD 25 - 75 HP	33	4,959	6,978	141%

Coincidence Factors

This evaluation has produced adjusted savings factors and coincidence factors for summer and winter peak demands. These savings factors should only be applied to future air compressor projects that use the updated TRM methodology including the kW per HP values from Table 3-9. This methodology would retain the existing algorithms, but would use the following components in the savings estimates:

- Rated HP
- kW/HP Savings Factor – VSD 25 – 75 HP, Load/Unload baseline results from this study
- Hours of Use Adjustment (kWh RR) – 141% from this study, applied in the TRM as a kWh realization rate
- Peak Coincidence Factors –Values for Summer and Winter On-Peak (See Table 3-11)

Table 3-11: Air Compressor Summer and Winter Peak Coincidence Factors

Compressor Type	Summer On-Peak kW CF	Winter On-Peak kW CF
All Air Compressors	1.00	0.82
Relative Precision at 80% Confidence	±9.38%	±11.65%
VSD 25 - 75 HP	1.05	0.83
Relative Precision at 80% Confidence	±10.46%	±15.12%

3.5.2 Refrigerated Dryers

3.5.2.1 Prospective Savings Factors

Average kW Savings

Table 3-12 provides the weighted average kW per CFM saved values for all refrigerated dryers. The table provides the weighted averages of the tracking value, which was derived from the gross kWh tracking savings, the calculated TRM value, and the evaluated value. Evaluators found that in some cases, the incorrect kW/CFM value was applied. The evaluated value was significantly higher than either the tracking or TRM values. The evaluation found that when the compressor systems operated, the new cycling dryers were off more often than estimated while the baseline, non-cycling dryers, would have run during all compressor hours.

Table 3-12: Dryer kW per CFM Saved

Equipment	Number of Dryers	kW Reduction per CFM Saved		
		Tracking Value	TRM Value	Evaluation
All Refrigerated Dryers	17	0.00382	0.00371	0.00558
			RP @ 90% Confidence	±22.5%
			RP @ 80% Confidence	±17.5%

Hours

The evaluation calculated average operating hours for all air dryers. Operating hours are defined as all hours the compressors are on, which are when the dryers would realize savings. These results are presented in Table 3-13 along with the weighted average tracking estimates for operating hours. The tracking hours are not stipulated in the TRM, but are based on site conditions obtained through interviews. As shown below, the evaluation found significantly higher operating hours from monitored dryer data as compared to the tracking estimates. These hours correspond with the air compressor hours presented earlier in the report.

Table 3-13: Weighted Average Dryer Operating Hours

Compressor Type	Number of Dryers	Tracking Hours	Evaluation Hours	Evaluated/Tracking Hours
All Refrigerated Dryers	17	4,460	6,944	156%

3.5.3 Zero Loss Condensate Drains

This study looked at all incentivized zero loss condensate drains that were included with the air compressor sample. The evaluation verified zero loss condensate drains at all of the 15 sites that had those (13 in MA and 2 in RI). One site was missing one of four of the incentivized drains. Overall, savings were recalculated by updating the compressor run hours component of the savings calculation with the compressor run hours from the monitored data. The result was that the zero loss drains were found to save approximately 99.7% of the estimated energy savings across the 15 sites.

It appears that the drains are installed and seem to be working properly, but performance was not assessed.

3.6 Conclusions

This evaluation found that savings from all three prescriptive compressed air measures are being realized. The air compressor measure produced an energy savings (kWh) realization rate of 118%. This value was driven by VSD air compressors, which performed much better (121%) than the load/unload air compressors (12%). However, it should be noted that there was only one (1) load/unload air compressor in the sample. The high VSD compressor realization rates were primarily the result of higher than anticipated operating hours.

The dryer measure yielded an energy savings realization rate of 156%, which was driven by both a higher average kW reduction per CFM, and higher operating hours. The largest savings increase came from the largest dryer category (>400 CFM). This dryer category included five dryers, which were all part of compressed air systems that operated 24/7.

The zero loss condensate drains appear to be installed as expected. Though this equipment was not monitored, evaluators verified the installation of almost all drains that were incentivized. This evaluation does not recommend any adjustments to the zero loss condensate drain measure due to a small sample size.

3.7 Recommendations

3.7.1 Air Compressor Baseline

The evaluation calculated air compressor savings using two different baselines, including the current modulating baseline with blowdown and a load/unload baseline. Though the results did not vary significantly between the two, this evaluation recommends updating the baseline to a load/unload baseline going forward. A recent incremental cost study[8] found that the cost of a modulating air compressor is nearly the same as a load/unload air compressor, and that the load/unload air compressor is now considered the baseline compressor. This finding was based on interviews with four compressed air sales representatives. The results of this study show that the savings opportunities from going from a modulating to load/unload system are minimal except at higher storage levels for the load/unload unit.

3.7.2 Application of Results

This study produced new savings factors for air compressors and refrigerated dryers to be used prospectively, as shown in Table 1-7. These savings factors, which are calculated based on the average operating kW of the sample of air compressors and dryers, may be used to update the values from the TRM. This table includes the savings factors for both baselines. Should the program switch to a load/unload baseline, the TRM should use the new load/unload values.

Table 3-14: Air Compressor and Dryer kW Savings Factors

Equipment	Air Compressors		Refrigerated Dryers
	kW Reduction per HP (Modulating w/ Blowdown)	kW Reduction per HP (Load/Unload)	kW Reduction per CFM
All Air Compressors	0.125	0.127	N/A
VSD 25 – 75 HP	0.181	0.190	N/A
All Refrigerated Dryers	N/A	N/A	0.00558

It is also recommended that National Grid apply the new air compressor coincidence factors to both the zero loss condensate drain and low pressure drop filter measures, since the savings for these measures occur during compressor operation.

3.7.3 General Recommendations

Recommend compressed air vendors conduct simple short term metering. Customers often don't know how their air compressors operate during off-shift periods. While the customer may be able to accurately report the hours of normal shift operations, compressed air systems nearly always have some leaks or other air users that, if not shut off, the compressor will continue to feed during off-shift hours. While this is a prescriptive program, which is intended to be streamlined, collecting very simple

[8] Navigant, Northeast Energy Efficiency Partnerships Inc. (NEEP) Incremental Cost Study Phase Four Final Report. June 15, 2015. P. 21.

short-term data prior to specifying hours of operation on an application would help improve the accuracy of the annual hours of operation. This type of metering could be done by the vendor, and could be a simple as a week of motor runtime. Another option would be to investigate the incremental cost of adding monitoring at the time of compressor installation as part of the incentive package. Compressed air system monitoring would help operators understand and manage their air use while providing the industry with more compressed air energy data.

Consider a review of interval load data prior to finalizing applications. In many cases the actual operating hours were observed to be significantly higher than entered on the application form, resulting in unclaimed savings. For applications with relatively low operating hours (<~4,000 hrs/yr), it may be worthwhile to perform a brief interval load data review to confirm actual plant operating hours. Compressors are often a significant percentage of a facility's energy consumption and operation is noticeable in the interval load data. Increased operating hours result in increased savings from a higher efficiency compressor.

Encourage vendors to look for additional compressed air savings opportunities. In most cases the compressors appeared to be operating at the same discharge pressure as prior to installation based on discussions with facility personnel. While the customer is engaged with upgrading their compressed air system, it may be worthwhile to investigate operation at a lower discharge pressure. Additional savings will result if the discharge pressure can be reduced. Likewise, consider performing an air leak survey to determine if additional savings can be realized from reducing air leaks. Reducing leaks may, in some cases, result in being able to purchase a smaller compressor saving more money. These types of improvements are covered by the custom program, and may result in moving some prescriptive air compressor projects to custom.

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